High efficient cryogenic disk laser with sub-joule energy level and kilohertz repetition rate

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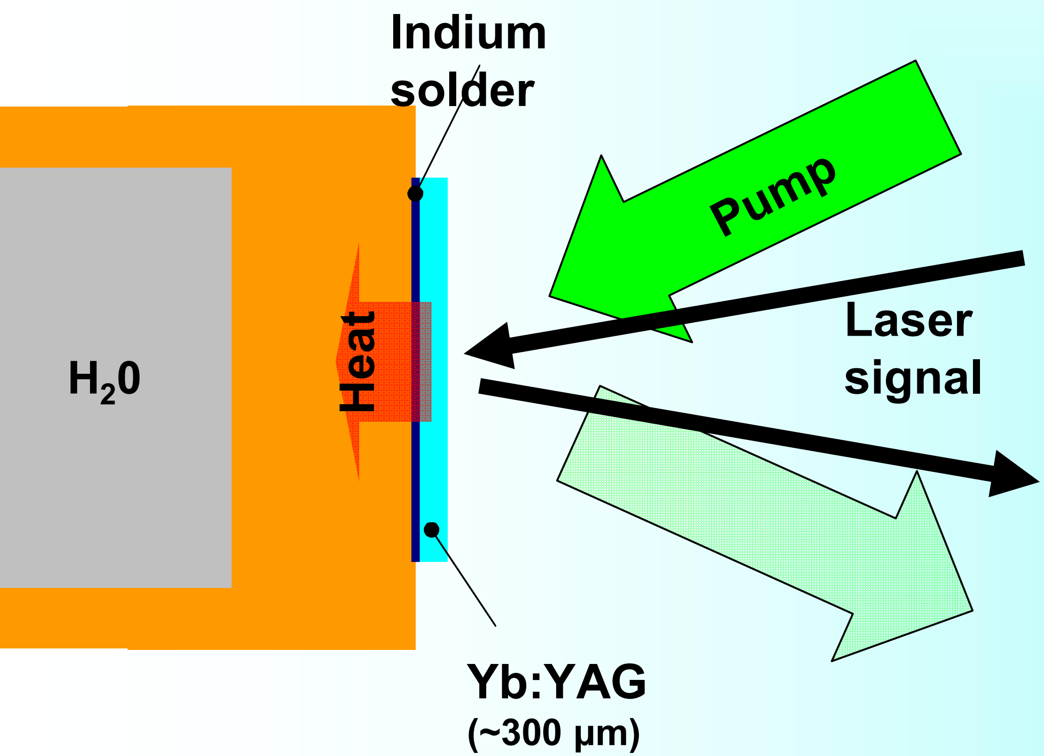
1. Specificities of cryogenic disk lasers

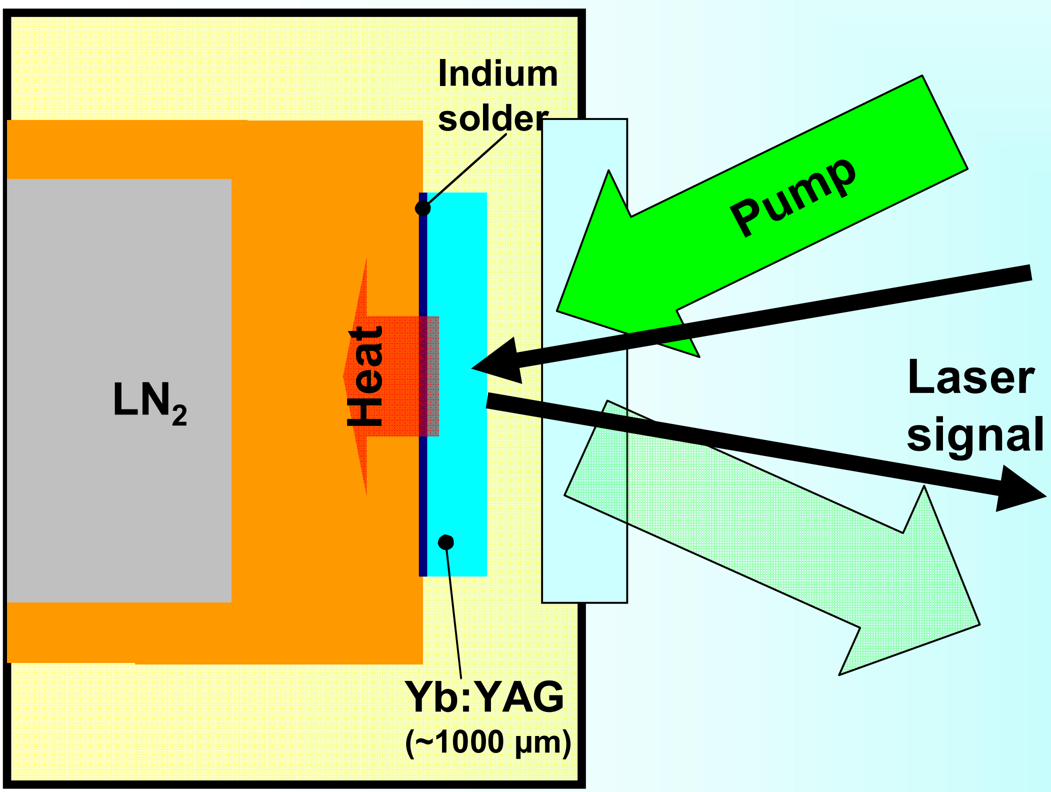
Ambient temperature thin disk laser is not a good way for high energy capacity lasers due to small thickness and doping of active media



- ✓High average power
- ✓ Good heat removal
- ✓Simple scaling
- ✓Small signal gain is about 1.1-1.2
- ✓Many passes of pump and signal
- ✓Very small volume of active media

1. Specificities of cryogenic disk lasers

Cryogenic disk laser is more suitable, but there are a lot of troubles too!



- ✓Thermooptical distortions are significantly reduced
- ✓There is no any population on lower laser level
- ✓Thin disk becomes thick disk and Stored energy may be increased
- ✓1-2 passes of pump through the thin disk
- ✓Strong ASE
- ✓Troubles with LN2 boiling
- ✓Troubles with mounting because of different CTE

1. Specificities of cryogenic disk lasers

So, what we need take to account to develop a cryogenic disk laser with high energy capacity and average power?

✓Maximal energy/power product may be achieved at ~ 1 kHz repetition rate for Yb-doped media

✓We need carefully design disk shaped active elements to save a stored energy/ reduce ASE

✓Disk active elements with undoped cup and cladding may be used to reduce ASE and parasitic oscillation

✓It is necessary to realize active liquid nitrogen cooling at high average power regime

✓It is necessary to solve troubles with different CTE, vacuum pumping and etc.

2.1 Investigation of amplification and energy storing in disk shaped active elements

The numerical model of energy storing in Yb:YAG crystal is developed.

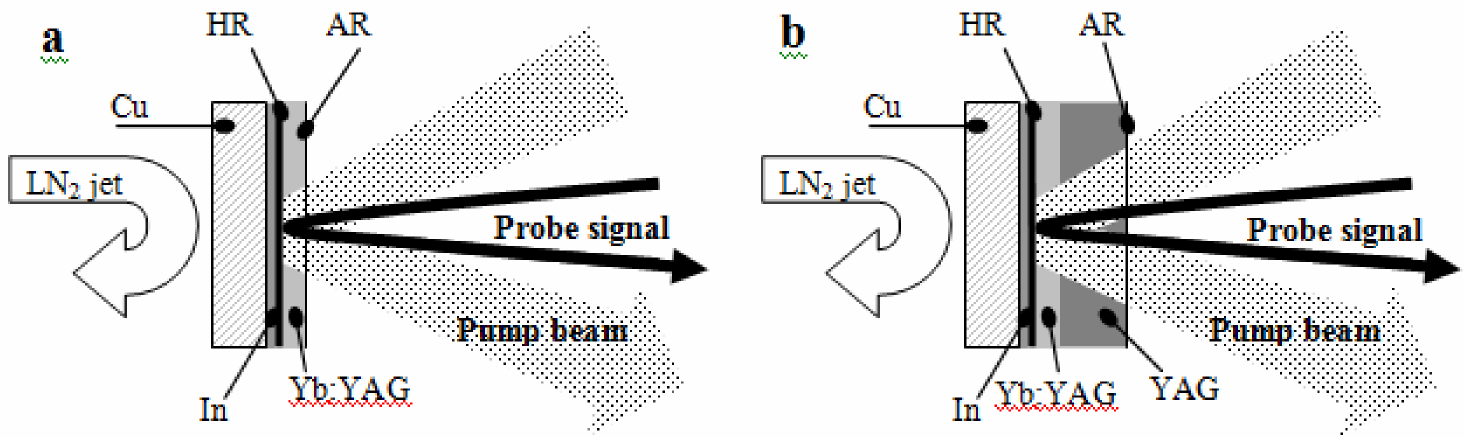
✓Two geometries are taken to account: disk (a) and disk with undoped cup (b)

✓Nonlinear heat equation is calculated in 3D geometry

✓Amplified Spontaneous Emission is calculated for 3D non uniform inversion with tacking to account spectral distribution of emission cross section

✓Laser and spectral characteristics of Yb:YAG are investigated in 80-400 K range

✓As a result, It is possible to calculate stored energy at high thermal load, high temperature range, any geometry (from thin disk to rod)

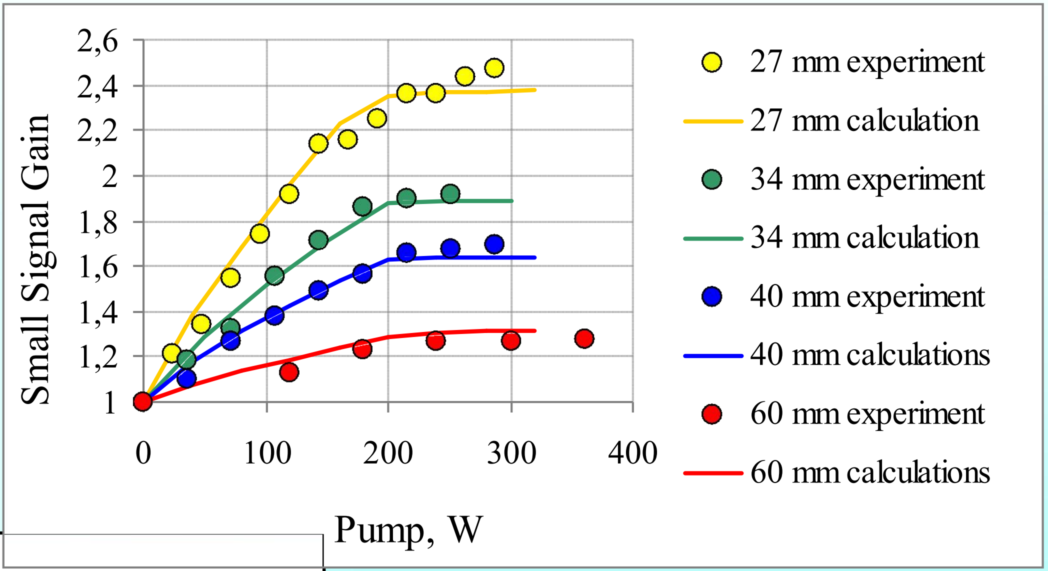


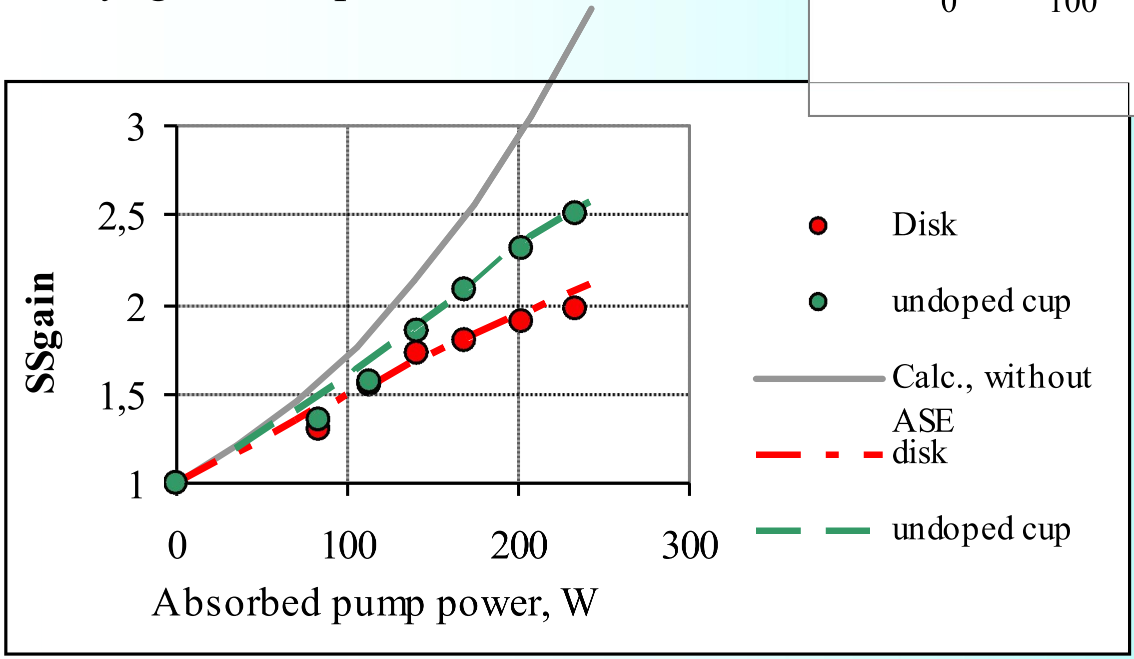
2.1 Investigation of amplification and energy storing in disk shaped active elements

The small signal gain is measured in different disk shaped active elements.

✓A good agreement between experimental and simulation results (with taking to account a parasitic oscillation)

✓Comparison was made at cryogenic temperatures



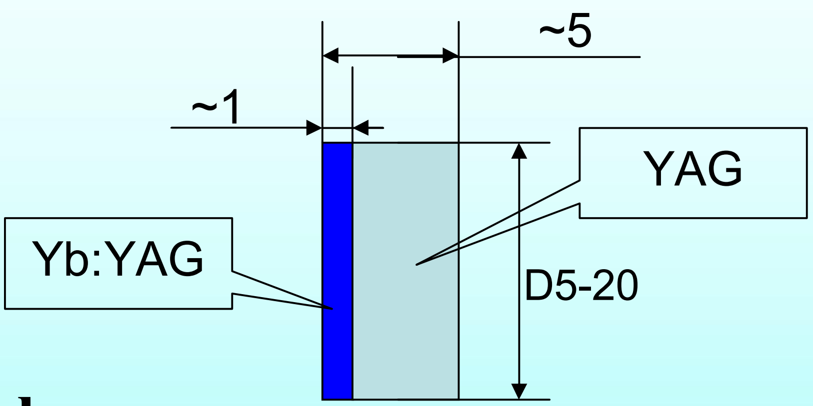


✓Disk with undoped cup is more suitable for HEC DPPSLasers

✓The storing efficiency will be decreased at SSgain increasing in any case of geometry

2.2 New technique of thermal bonding of composite active elements

Our motivation is the developing of Yb:YAG/YAG "sandwiched" elements to ASE reduction and effective cooling.



Basic requirements for composite samples:

- ✓The active element must be not damaged at cooling to 80K
- ✓The strength of contact must be comparable with YAG medium at high thermal load
- ✓There is no any losses of passed radiation in the contact layer
- ✓The contact layer must be very homogeneous
- ✓New method must be allow to fabricate large aperture active elements
- ✓Method of bonding must be simple and not expensive

2.2 New technique of thermal bonding of composite active elements

The keys of new method are the use of orthophosphoric acid to active bonded surfaces and thermal diffusion bonding after that

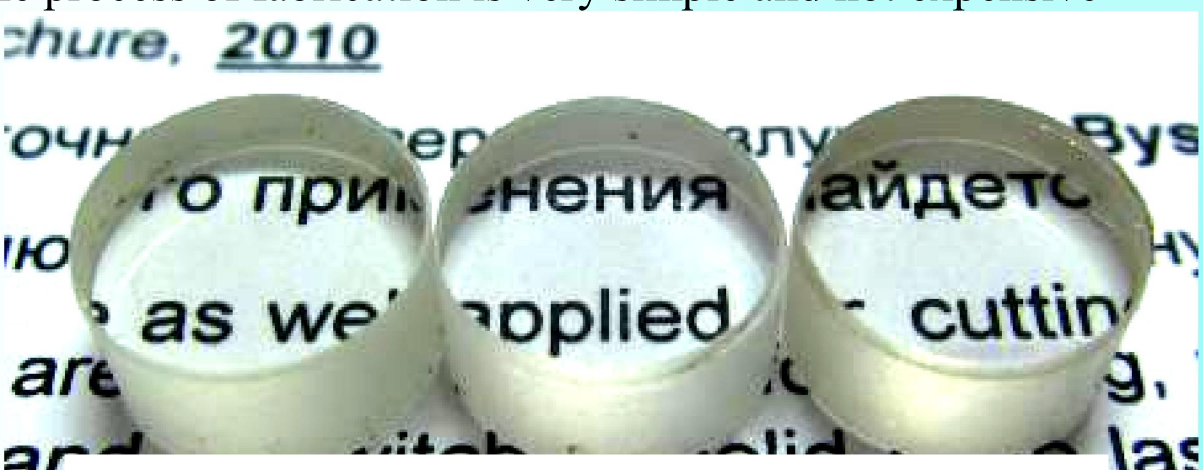
✓Thermal diffusion bonding provide a high strength of bonded layer

✓Liquid phosphates allow to realize an excellent optical contact in conditions of not excellent polishing/high aperture samples

✓ At heating process we don't use any pressure because phosphates goes to phosphate glass at several hundreds degrees

✓Nano thin layer of phosphates (several nm) is diffused in YAG volume further heating

✓As a result, the process of fabrication is very simple and not expensive

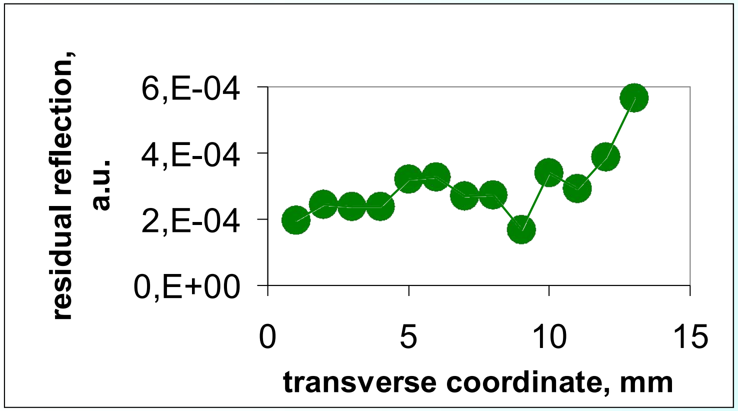


The picture of bonded samples

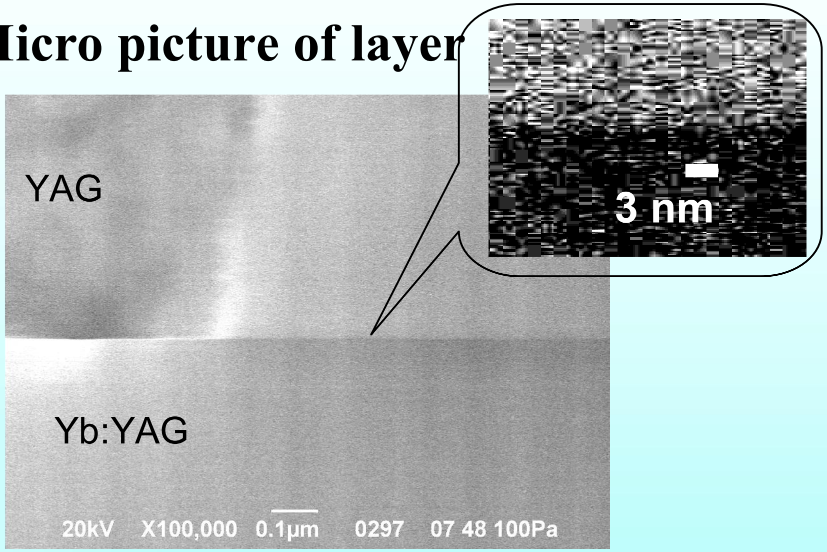
2.2 New technique of thermal bonding of composite active elements

Several tests of the contact quality were made

Residual reflection from contact layer



Micro picture of layer



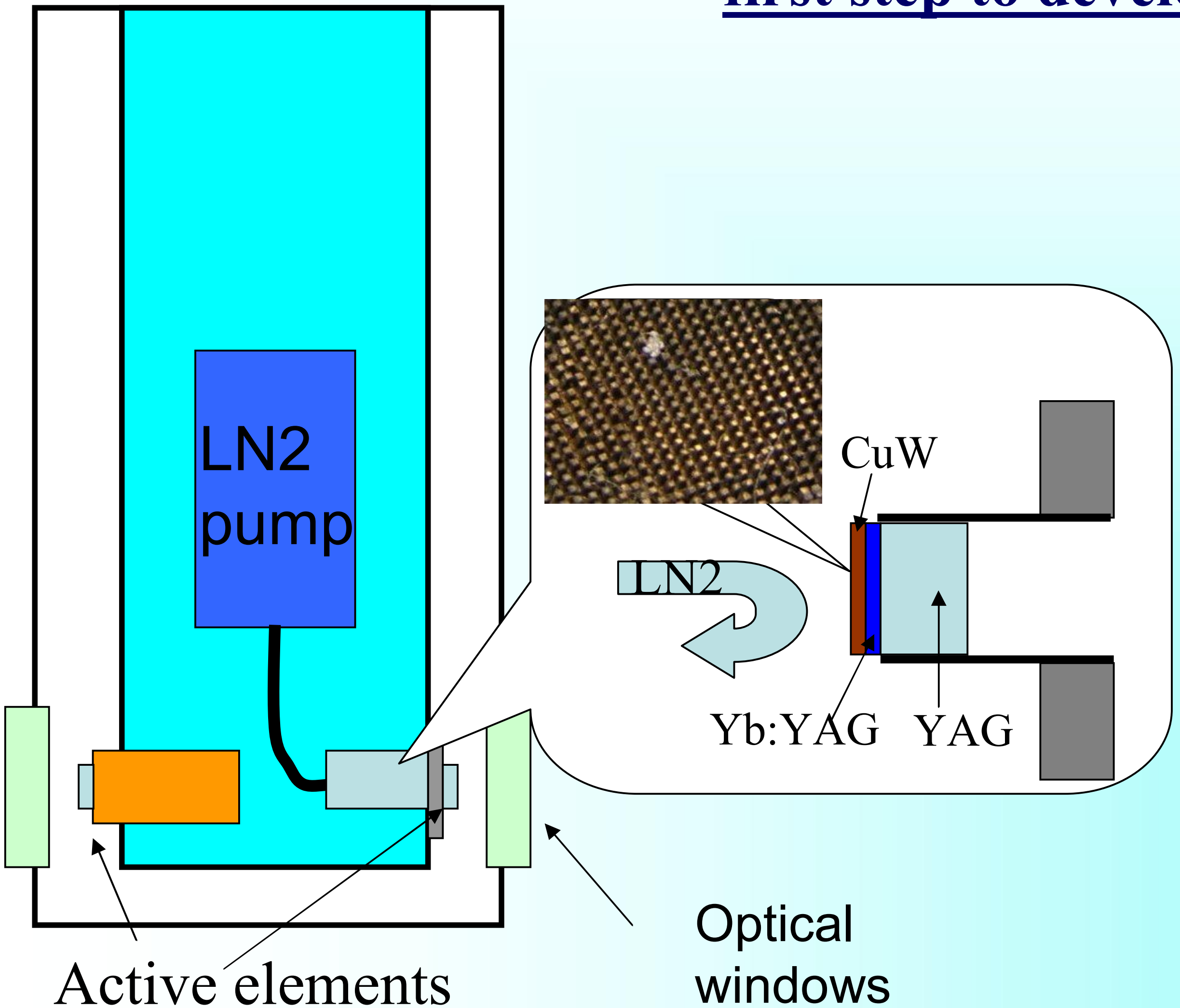
"Crush" test by pump

Several tests at cryogenic temperatures:

- ✓Lasing
- ✓Amplification
- ✓Amplification at high thermal load
- ✓Emission cross section and life time measurement

2.3 Efficient cooling of active elements by liquid nitrogen jet

We tried a simplest design of cooling by liquid nitrogen jet as a first step to develop an active cooling

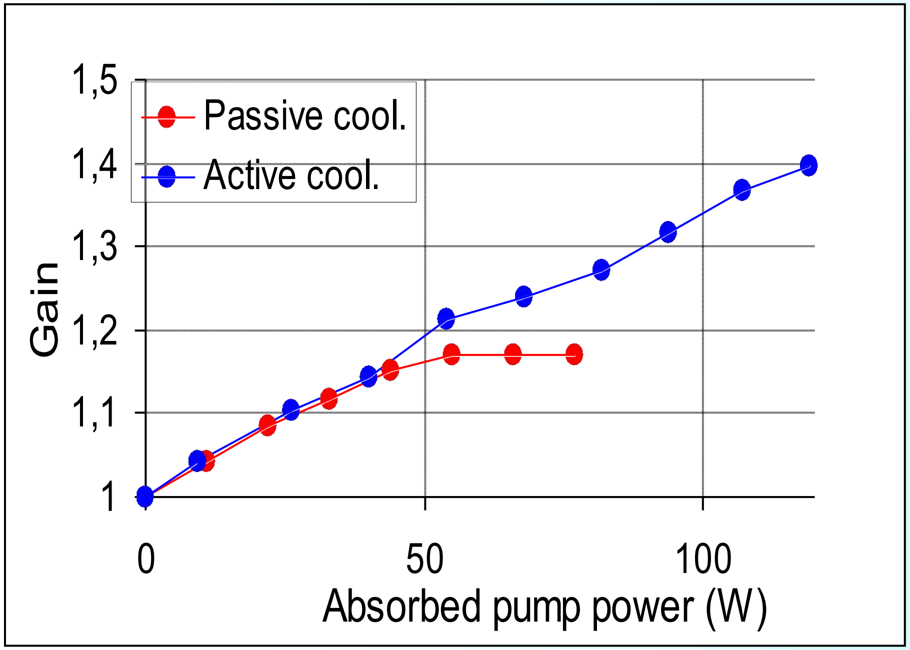


- ✓Just disk with undoped cup are suitable for active cooling on our geometry
- ✓CuW is thin (~1 mm) to avoid distortions
- ✓Back side of CuW has a cutting
- ✓The working of LN2pump leads to small vibrations
- ✓A new system of active cooling without LN2 tank is under developing

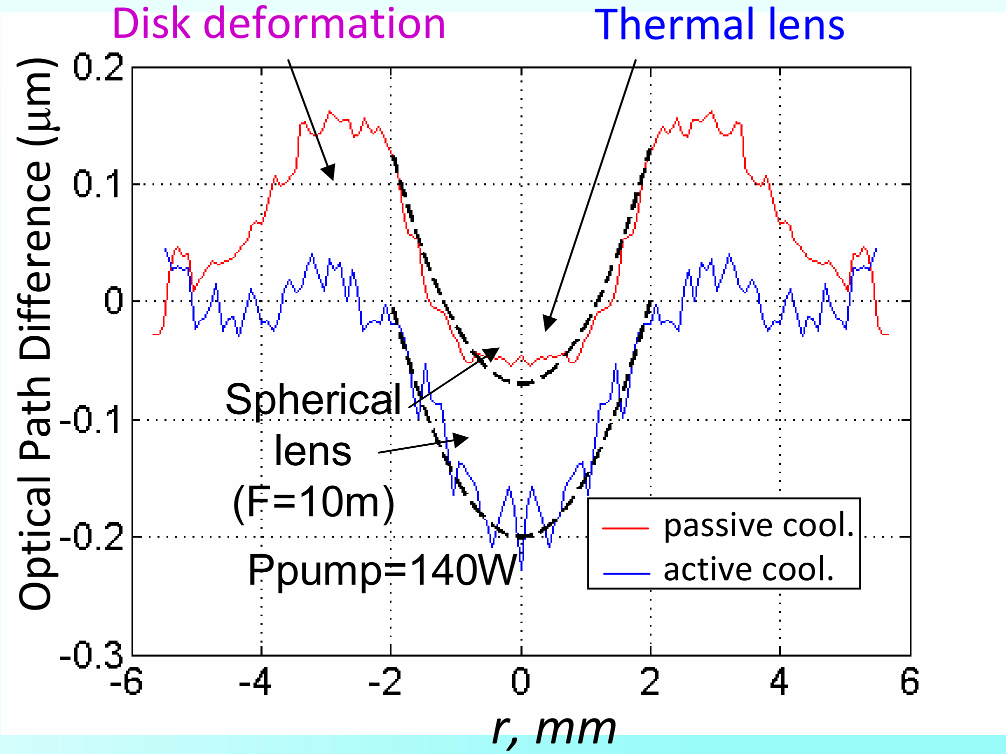
2.3 Efficient cooling of active elements by liquid nitrogen jet

Active cooling allows to increase a pump power

Small signal gain



Small signal gain



3. Current status of cryogenic disk laser development in IAPRAS

- Ps thin disk laser
- Yb:YAG cryogenic disk amplifier
- <100 ps of pulse duration
- 1-5 mJ pulse energy at 1kHz repetition rate

Project goal

1. >0.5J
2. <100 ps pulse
3. ~1 kHz repetition rate
4. ~500 W average power

Seed laser system

- The Yb:YAG disk active mirror
- 50 mJ amplified pulse
- ~10 passes of the beam with D = 3-4 mm, small signal amplification a_0L=0.5-0.6
- 150-300 W pump power, 77 K temperature

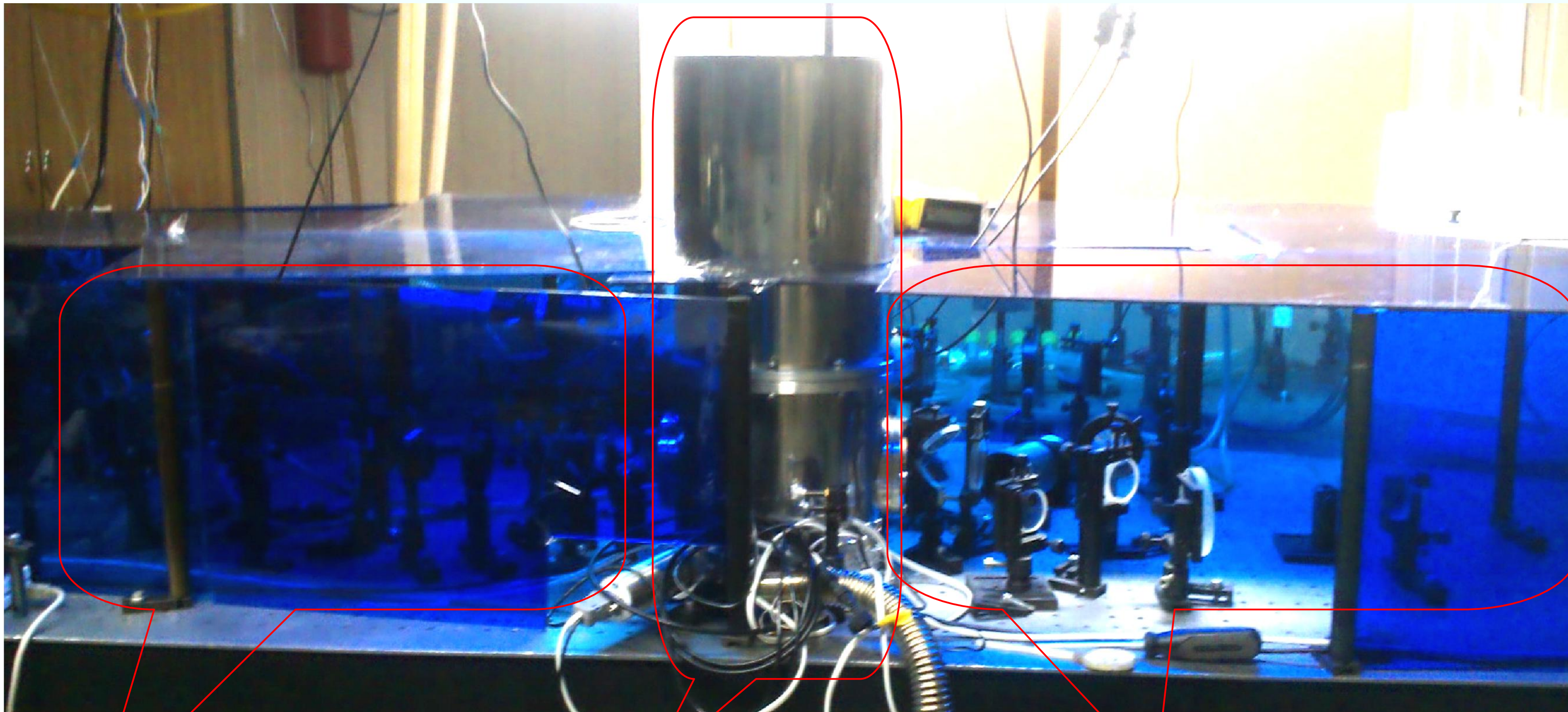
Cryogenic disk preamplifier

- Two Yb:YAG active mirrors,
- 500 mJ amplified pulse
- 8(16) passes of the beam with D = 8-12 mm, small signal amplification a_0L=0.25-0.45
- 2×(08-1.2) kW pump power, 77 K temperature

Cryogenic two disks main amplifier

3.1 Seed laser and booster amplifier

First two stages of laser system



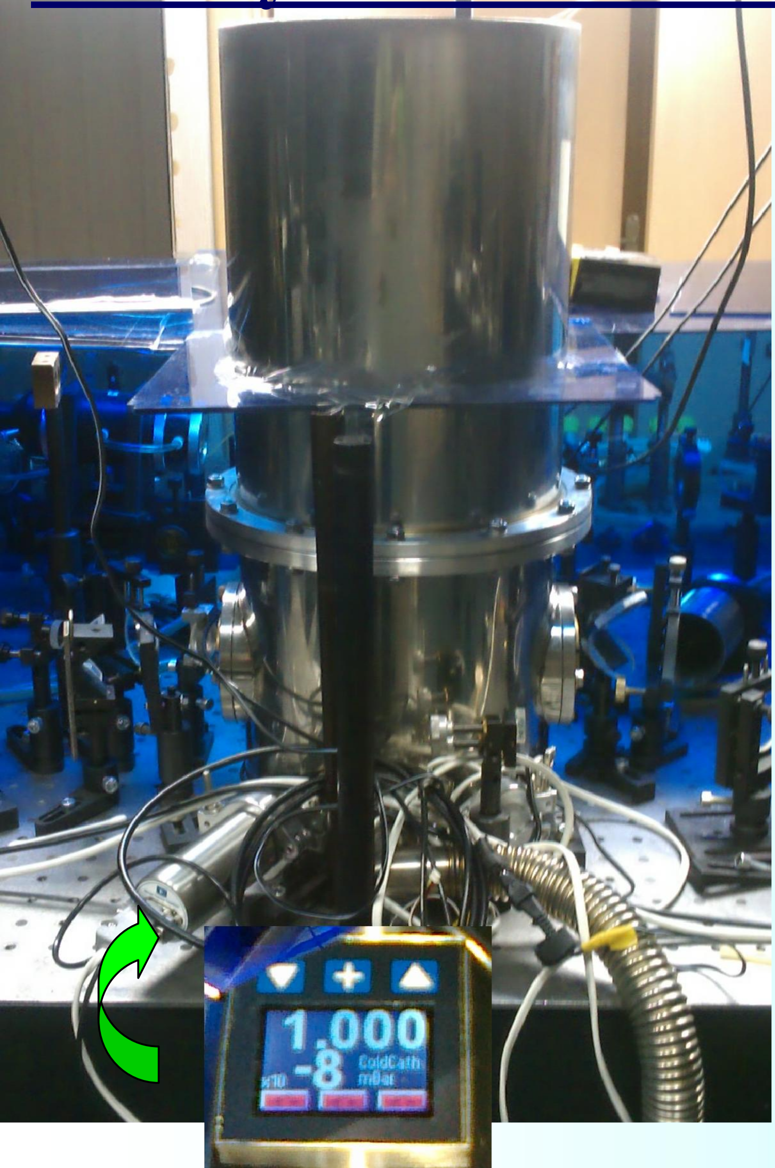
Master oscillator

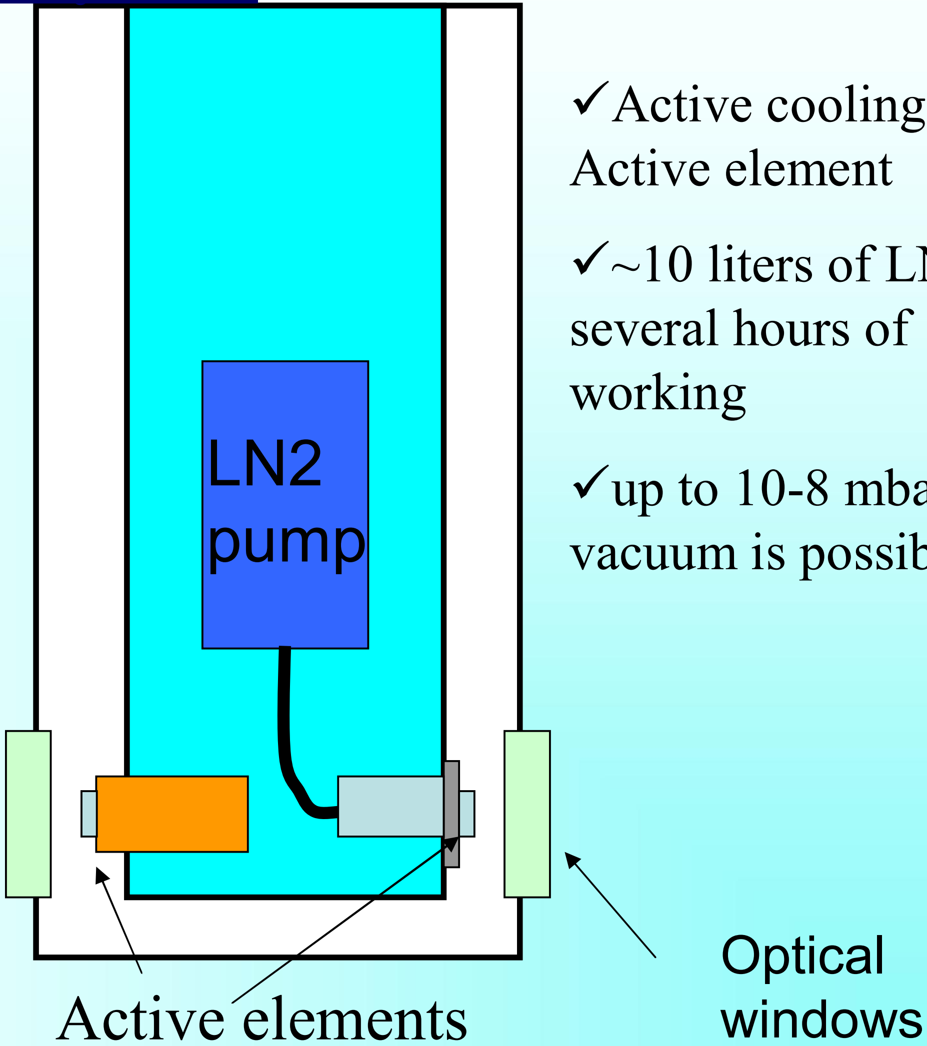
LN2 cryostat

Booster amplifier

3.1 Seed laser and boost amplifier

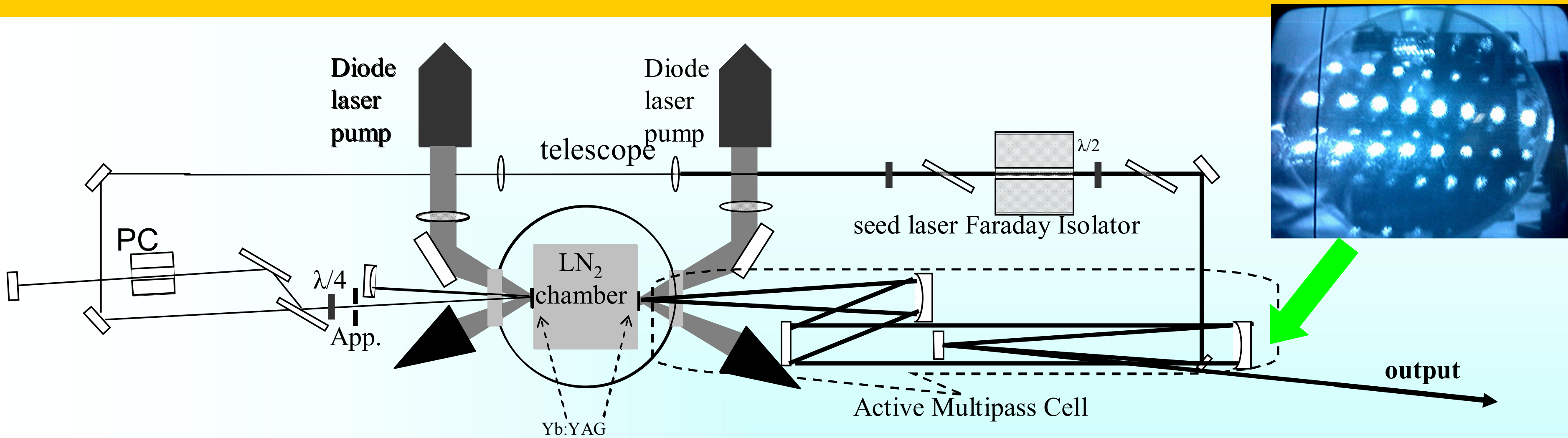
LN2 cryostat for MOPA system





- ✓Active cooling of one Active element
- ✓~10 liters of LN2 for several hours of working
- ✓up to 10-8 mbar vacuum is possible

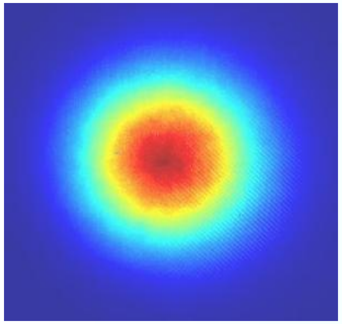
3.1 Seed laser and boost amplifier



- ✓Disks with and without undoped cup are tried
- ✓5% doped Yb:YAG with 1.4 mm of thickness
- ✓~ 3mm pump spot diam. in booster amplifier
- ✓2 V passes of the pump
- ✓Active cryocooling by LN2 jet in booster amplifier
- ✓“Active Multipass Cell” amplification scheme with 9 V-passes

Joerg Neuhaus at all, Passively mode-locked Yb:YAG thin-disk laser with pulse energies exceeding 13 μJ by use of an active multipass geometry, OPTICS LETTERS / Vol. 33, No. 7 / April 1, 2008

3.1 Seed laser and boost amplifier

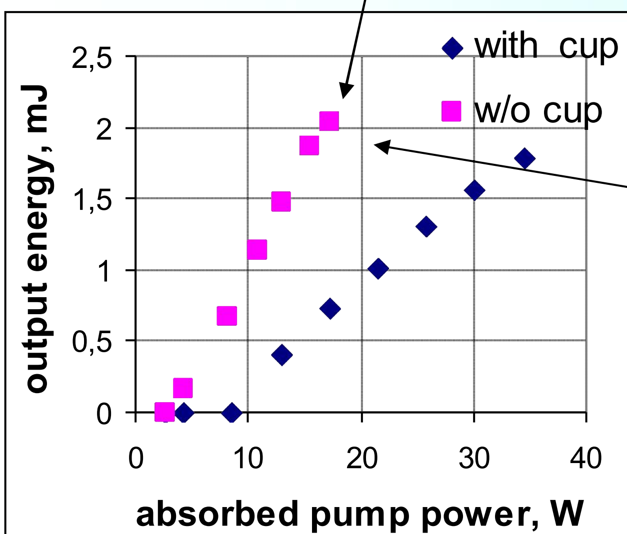


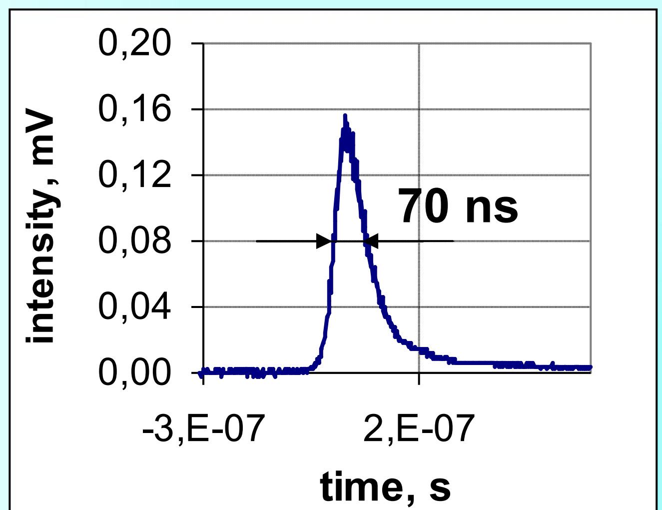
The beam from MO

Limited by optical damaging

Master oscillator output parameters:

- ✓2 mJ of energy
- ✓70 ns pulse length
- ✓1 kHz repetition rate
- ✓Good beam quality
- ✓Excellent stability is close to 1% through 2 hours!

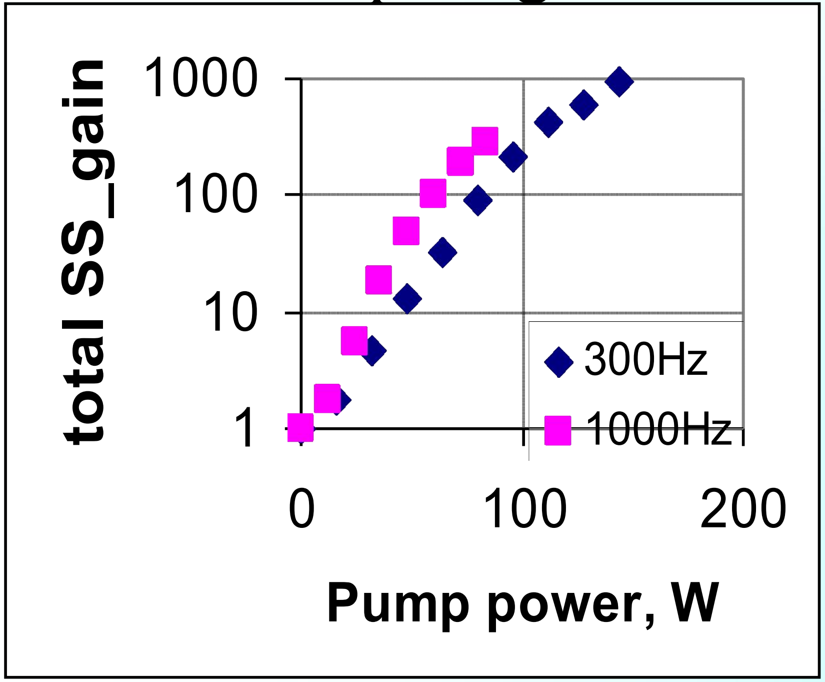


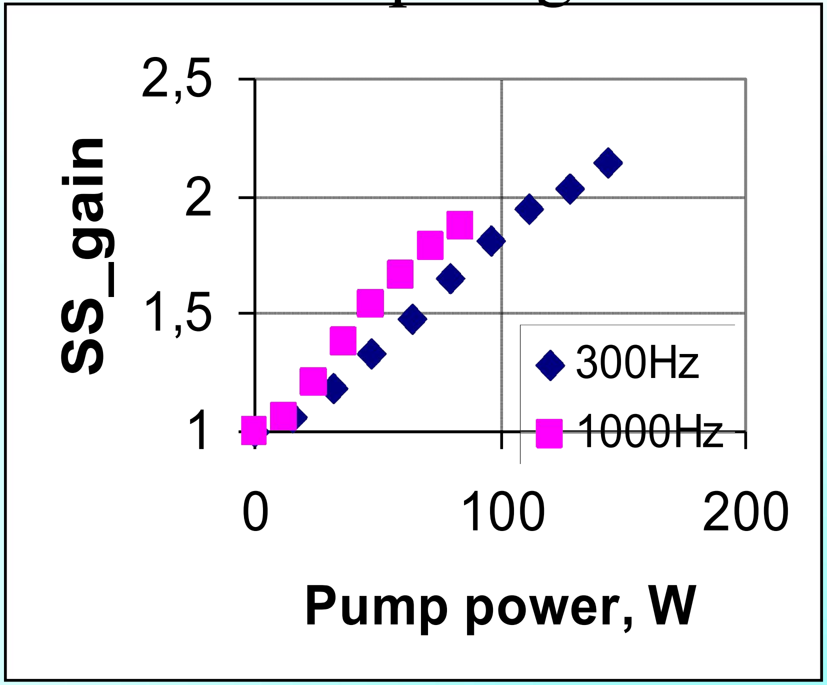


3.1 Seed laser and boost amplifier

Small signal gain in boost amplifier

Total 9 V-pass gain and one V-pass gain



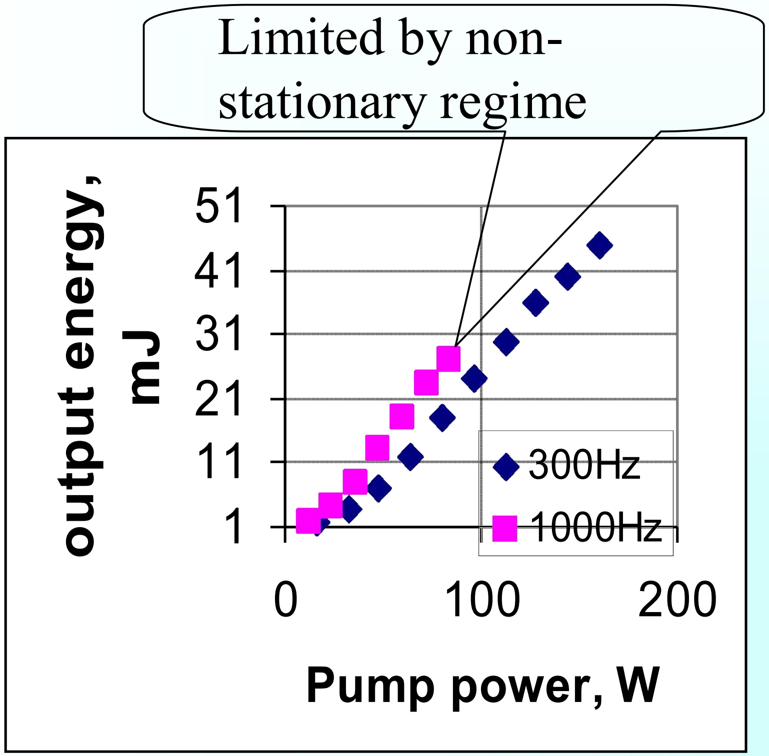


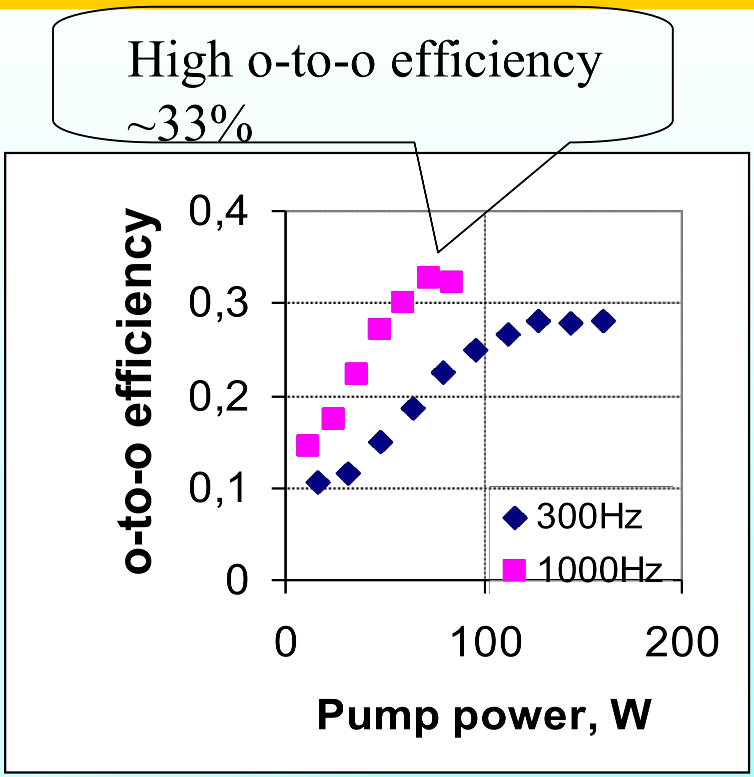
✓1000Hz – CW pump, 300Hz – 1 ms pulsed pump

✓Small signal gain is larger at CW regime due to larger time of energy storing

✓ Very large total gain is achieved in multipass geometry. It may be good alternative for regenerative amplifiers

3.1 Seed laser and boost amplifier





✓ Up to 33% o-to-o efficiency is achieved. There is a higher efficiency at CW pump due to saving of residual energy for the next pulse

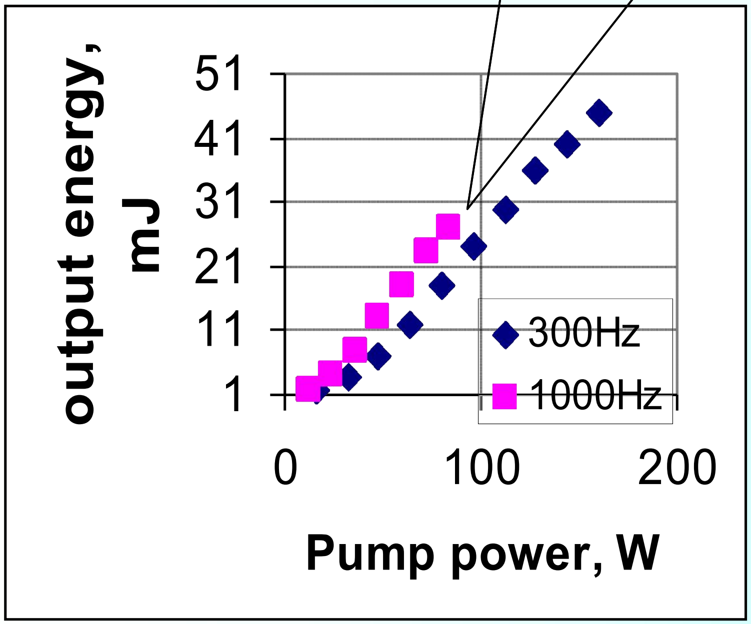
✓The efficiency is limited by losses (~ 25%) in the AMC-scheme (basically in the optical window of the cryostat) and can be increased to 40-50% by reducing losses and more suitable active element

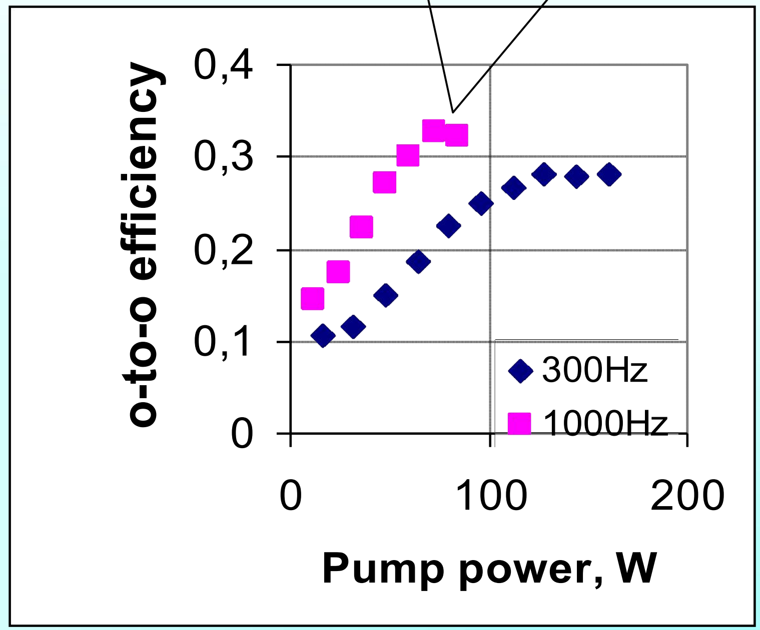
[J. Korner at all, „High-Efficiency Cryogenic-Cooled Diode-Pumped Amplifier with Relay Imaging for Nanosecond Pulse", HEC-DPSSL Technical Digest, 2010]

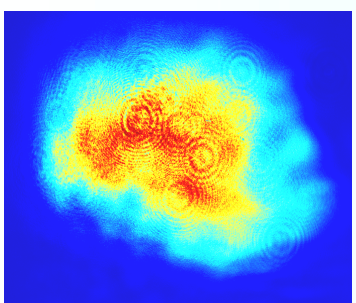
3.1 Seed laser and boost amplifier

Limited by non-stationary regime

High o-to-o efficiency ~33%







Near field of 27 mJ pulse at 1 kHz

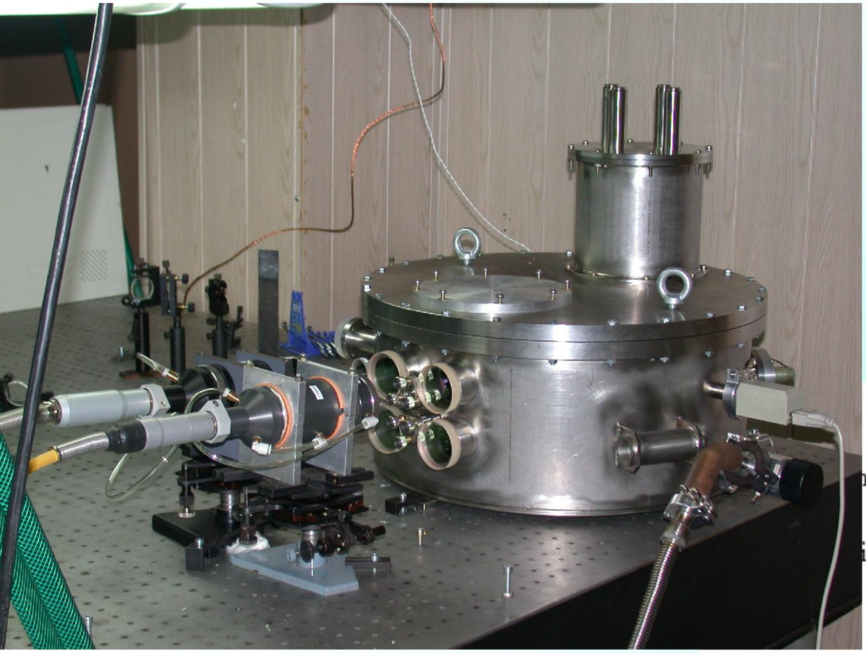
✓Up to 27 mJ at 1 kHz and 47 mJ at 300Hz is achieved

✓Pulse-to-pulse stability about 3%

✓The beam quality is dropped, but it can be solved by spatial filtering and more suitable heat sink

3.2 Cryogenic disk amplifier based on Yb:YAG ceramics

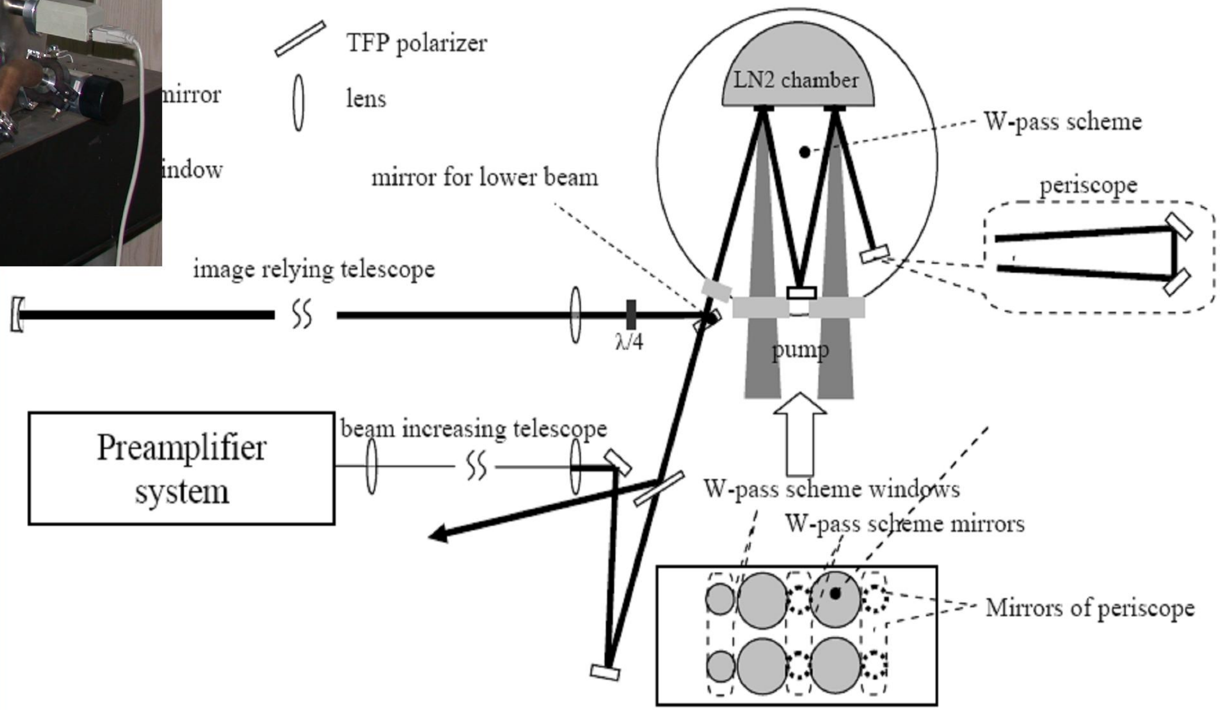
Picture and optical scheme of main amplifier



✓Disks without undoped cup and active cooling were used

✓The optical scheme is very sensitive to thermal distortions

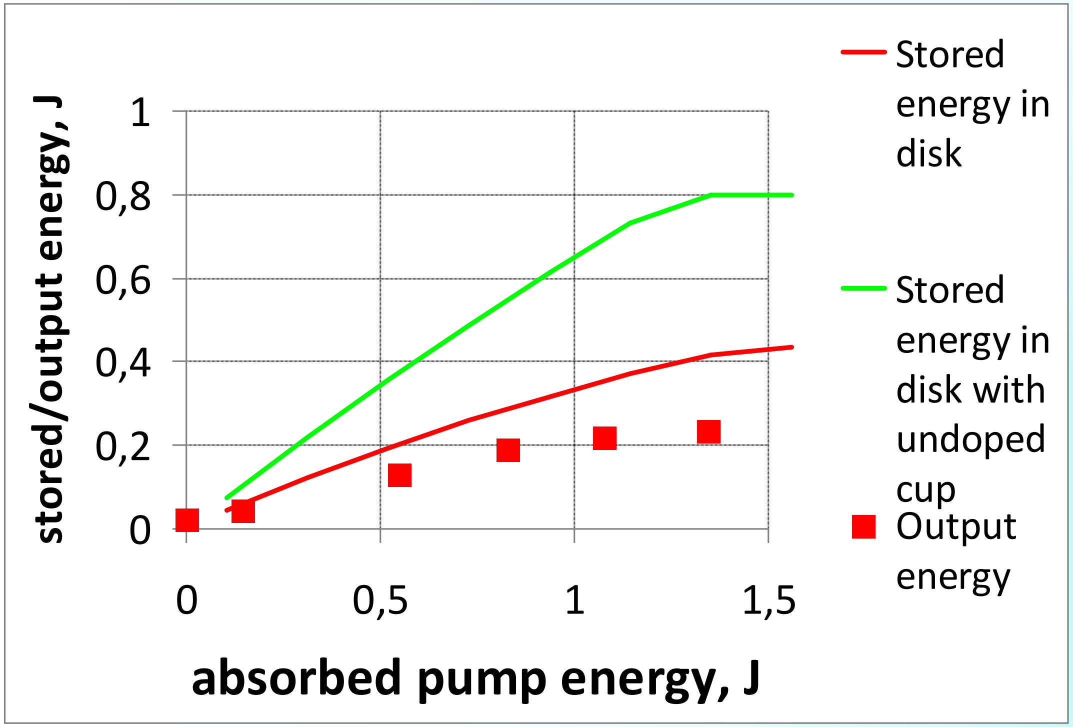
✓Pump duration 1.3 ms at 150 Hz



Yb:YAG ceramic samples fabricated by Research Scientist of Temasek Laboratories @ NTU, AMRC LAB, Nanyang Technological University, Singapore

3.2 Cryogenic disk amplifier based on Yb:YAG ceramics

Current results for output parameters of a laser



- ✓Up to 0.24 J at 150Hz repetition rate is achieved
- ✓o/o efficiency is ~20% with extracting efficiency of stored energy ~ 60%
- ✓Repetition rate was limited by thermal lens
- ✓Stored energy was limited by ASE and parasitic oscillation
- ✓The using of undoped cup allow to increase stored energy by factor of 2
- ✓As a result, it is possible to have 0.5 J output with ~35% efficiency

Next upgrade of a laser system

Energy/power increasing

✓Active elements with undoped cup already fabricated with clear aperture 20 mm

✓Active LN2 cooling is under development

✓Optical scheme will be changed on image relaying scheme like in booster amplifier

Pulse length decreasing

✓New coatings are tried with 20J damaging threshold at 10 ns

✓The pulse length will be decreased to 5 ns at the next upgrade

✓The developing of fs laser system is started to use as a seed source for cryogenic disk laser and OPCPA stages

Summary

- Several activities which are very important for High energy an power cryogenic lasers are elaborated in IAPRAS
  - ✓Stored energy calculation activity to correctly design active elements
  - ✓The fabrication of disk shaped elements with undoped cup by thermal diffusion. We believe, that new method has no limitation in aperture
  - ✓Active cryogenic cooling is important technology for any cryogenic laser with high average power
- Cryogenic disk laser is under development in IAPRAS
  - ✓We develop laser with best energy/power product choosing CW pump and 1 kHz repetition rate
  - ✓Up to 33% o/o efficiency is demonstrated and efficiency may be larger
  - ✓Laser system is tried at 150 Hz with output energy 0.24 J. We will more close to our goal after next upgrade

Summary

•Several activities which are very important for High energy an power cryogenic lasers are elaborated in IAPRAS

✓Stored energy calculation activity to correctly design active elements

✓The fabrication of disk shaped elements with undoped cup by thermal

Thank you for your attention!!!!

✓We develop laser with best energy/power product choosing CW pump and 1 kHz repetition rate

✓Up to 33% o/o efficiency is demonstrated and efficiency may be larger

✓Laser system is tried at 150 Hz with output energy 0.24 J. We will more close to our goal after next upgrade